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THE RIPPLES OF THE BEDFORD AND BEREA FORMATIONS OF CENTRAL AND SOUTHERN OHIO, WITH NOTES ON THE PALEOGEOGRAPHY OF THAT EPOCH[1]

JESSE E. HYDE
Columbia University

THE BEDFORD AND BEREA FORMATIONS

The Bedford and Berea formations are respectively the lowest and second lowest members of the Waverly series of Ohio. They were formed either at the close of the Devonian or at the beginning of the Mississippian period. They can be traced continuously across the state along the outcrop, from the Pennsylvania line on the northeast to the Ohio River on the south and over broad areas under cover to the eastward. The Bedford is almost entirely a shale formation usually about 100 feet thick; the Berea is a sandstone roughly from 20 to 150 feet thick.

In northern Ohio, the Bedford is largely an argillaceous shale with sandstones present locally, the Berea a coarse, feldspathic sandstone; the two are separated by an erosion plane.[2] In southern Ohio the Bedford consists of interbedded sandstones and shales, the former sometimes greatly in excess, the Berea of similar sandstones with limited quantities of shale. The sandstones in both are fine grained and of exactly the same type while between the two there is a transition zone. It is now becoming evident that the geological history of these beds has been quite different on opposite sides of the state, although the relation of the succession in one area to that in the other is not yet known. The Berea of southern Ohio is only a phase of the Bedford of the same region, while that of northern Ohio is wholly distinct from the Bedford and probably from the southern Ohio Berea. However, as a sandstone formation, it is continuous across the state.

[1] Published by permission of the State Geologist of Ohio.

[2] Charles S. Prosser, manuscript.

In the area under immediate consideration, central and southern Ohio, the Bedford is from 90 to 100 feet thick, the Berea from 5 to 40 feet thick. In Scioto County on the Ohio large amounts of sandstone are found in the Bedford, but this diminishes to the northward so that there is much more shale in Pike and Ross counties, while in Franklin County there is practically no sandstone, except in the upper 10 feet where very thin layers appear in profusion. In Pike and Ross counties the sandstones are frequently limy. When present, the sandstones are in beds from a few inches to two or three feet thick, but the "shale" beds intervening between such beds, often several feet thick, are largely made up of very thin, hard, platy sandstones of which there may be 12 or 18 in a foot.

Exactly the same type of sandstone is found in the Berea of central and southern Ohio as in the Bedford, except that the lime disappears. In fact the Berea is distinguished from the Bedford of the region almost solely by the rather abrupt diminution in the amount of "shale." These shale beds are found to some extent in the lower part of the Berea and, just as in the Bedford, they carry the numerous, thin, platy sandstones. In other words, the lithological change from the Bedford to the Berea was almost wholly one of amount and not of kind of material.

THE OCCURRENCE OF THE RIPPLES

Ripples are seldom noted in the lower part of the Bedford. In southern Ohio they appear rather gradually near the middle, and throughout the upper half of the Bedford and most of the Berea they are present, sometimes in astonishing abundance. The surface of each of the very thin lamellae of sandstone is rippled, as well as of the thicker beds. In central Ohio they appear first in the thin sandstones at the top of the Bedford, but are confined almost wholly to the Berea. In central Ohio and as far south as Pike County, the ripples gradually disappear in the upper part of the Berea and they may be absent entirely in the upper 10 or 15 feet, which also may become slightly coarser.

Many localities can be found, especially in Pike County, where the streams have cut into the Berea grit or the upper part of the

Bedford, and flow for some distance over a rock floor composed of the strata of these formations. Bed after bed is exposed in descending order, each with a beautifully rippled upper surface, and where the stream cuts through one of the "shaly" beds as many as 12 or 18 may be encountered in a vertical thickness of one foot, each ripple-marked. The parallelism of these ripples is most strikingly shown where the gradient is such that the stream descends gently across such a series, each of the surfaces forming the creek bed for a distance, to be superseded presently by the next layer lower down.

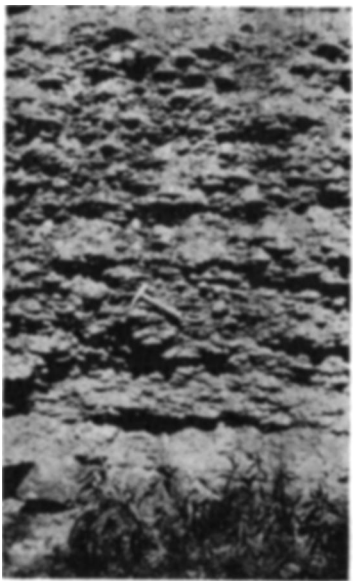

FIG. 1.—A portion of the upper part of the Bedford in the D.T. and I.R.R., cut southeast of Waverly, showing the many thin platy sandstones which largely make up the shaly portions of the formation. Each is rippled. Sometimes only the crests of the ripples are preserved as a series of lenses. The thicker sandstones are not present in this outcrop.

REVIEW OF PREVIOUS WORK

E. B. Andrews in 1870 first noted that the ripple-marks in the vicinity of Buena Vista trend in a northwest-southeasterly direction.[1] The formation in which they occur is not indicated and the context suggests that they are in the "city ledge" of the Cuyahoga, but they can only be in the Bedford and Berea, since ripples do not occur in the other.

Dr. Edward Orton, Sr., next called attention to the constancy of direction of these ripple-marks in Pike County. In his account of the geology of Pike County he says "the surfaces of successive layers, for many feet in thickness, are often covered with ripple-marks, all of them holding the general direction of north 53° west,

[1] *Geol. Surv. Ohio*, Rept. Progress [in 1869] in Second District, ed. of 1870, p. 68; ed. of 1871, p. 72.

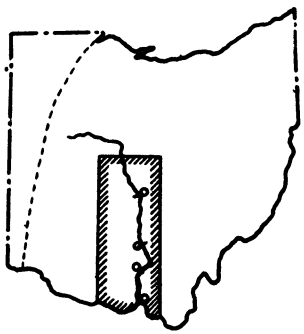

FIG. 2.—Outline map of Ohio showing area represented in large map of ripple directions, and general direction of the Cincinnati axis in Ohio (dotted line across western part).

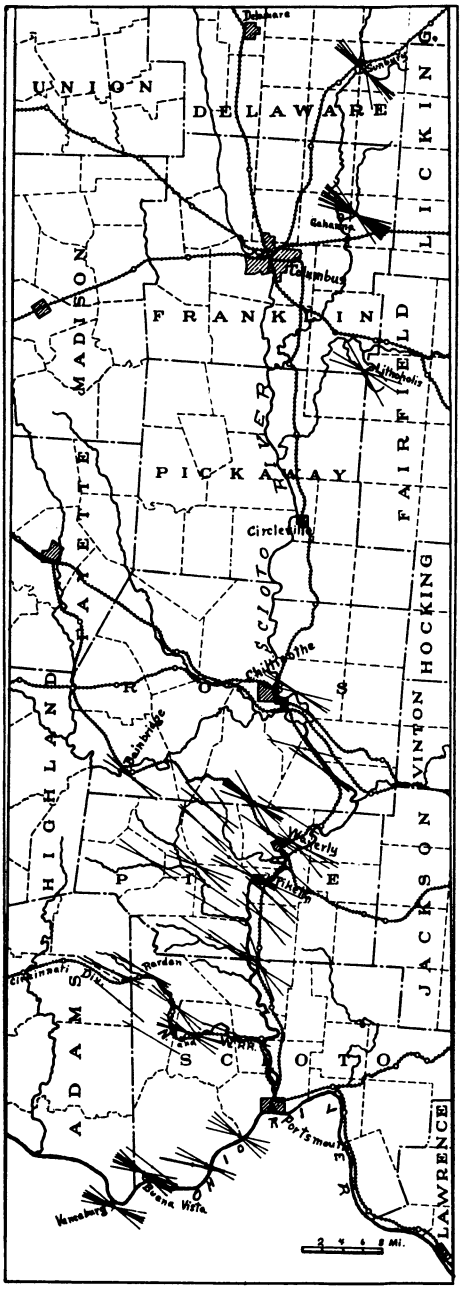

FIG. 3.—Map showing the ripple directions in the Bedford and Berea formations of central and southern Ohio

or south 53° east."[1] In a footnote to the last, he states that Mr. H. W. Overman, the county surveyor, made a careful series of measurements of these directions. "Of twenty-four observations, fourteen were found south 53° east. Four points showed south 65° east; one south 46° east; one south 57° east. The points that showed south 65° east overlie the other exposures, and probably indicate a real change of direction in the wave action."

THE NATURE OF THE RIPPLES AND THE PERSISTENCY OF THE RIPPLE DIRECTION

These observations which are given above in full suggested to the writer that further similar observations over a wider area might prove of value in the interpretation of the geography of the Bedford-Berea sea. Accordingly determinations of the direction of the ripple-marks in both the Bedford and Berea have been made sufficient practically to cover the whole of the outcrop in Scioto and Pike counties and most of Ross County, an area about 50 miles in length (from north to south) by 20 in breadth. Observations at three localities in central Ohio, Lithopolis, Gahanna (Rocky Fork), and Sunbury (Rattlesnake Creek), show that the same persistency continues to the northward, *a total distance from the Ohio River of 115 miles.*

The results of 149 observations have been merely to confirm Orton's observation on the original much smaller area, as to the general direction of the ripples. However, his statements as to the extreme persistency of the 53° angle are not borne out, and, if the area as a whole is considered, no tendency is apparent on the part of the higher surfaces to carry ripples trending more nearly east and west, as he seems to have found them.

At all points where several rippled surfaces are exposed, variation in direction is found, and not infrequently where one surface is exposed continuously for some distance, considerable change may be found in the direction of the ripples which cover it. This, of course, is to be expected. Not infrequently a range of five or ten degrees will be found on an outcrop showing possibly only six or eight surfaces; indeed, as great a range can be found in one ripple

[1] *Geol. Surv. Ohio*, Vol. II, Part 1 (1874), 620.

within a few feet along its length. Just below Denver in Pike County, two widely variant sets of ripples were observed on adjacent planes less than an inch apart, one trending N. 28°[1] W., the other N. 55° W. Such an extreme difference is unusual, but differences of six or eight degrees between adjacent planes can be found without effort. The greatest range noted at any locality is 43°, in the Berea grit below Denver in Pike County. The widest extremes found in the area from Chillicothe southward are N. 22° W., and N. 78° W., a range of 56°. The latter has been recorded several times, especially in the southern part of the area, but the former is an unusual direction. It was found on one plane in the Berea north of Clifford, Scioto County, associated with a number on which N. 60° W. was markedly dominant. In the central Ohio outcrops the extremes are N. 9° W. (on three superimposed planes at Sunbury) and N. 78° W. at Gahanna. This is the absolute range for the whole region, 69°.

Most of the ripple directions noted in the course of the present work have been drawn in on the accompanying map. (Fig. 3.) At some points where a number of directions have been noted, not all are plotted, but in every case where more than one direction has been found, the extremes have been drawn in. On the other hand, at many localities where the ripples persistently trend in one direction, only one observation is plotted, and at almost all points where considerable variation is indicated some one direction lying between the extremes is certain to be dominant, although not so indicated. Thus the map is really a map showing *extremes* of ripple direction, not only areally but vertically. If the directions were drawn in, in the order of their persistency, the amount of variation which exists would largely be obscured, and the unity of the direction would be much more impressively set forth. As it stands, however, it is sufficient to indicate clearly that some factor must have controlled the ripple direction in central and southern Ohio during the time when the upper part of the Bedford and Berea were accumulating.

The ripples are entirely (so far as observed) of the oscillation

[1] Observations are all compass readings. The magnetic declination is one degree or less west of the true north (determined in 1906).

type, that is, formed by the slight forward-and-back motion of the water which is caused by the passage of a wave. Not a single occurrence has been noticed which suggests typical "ripple-drift," the type of ripple which is produced by strong currents of water moving in one direction. The ripple crests are usually from three to five inches apart and rarely reach six inches. This interval varies within a few feet on any surface.

Considerable experimental work has been done on the ripple-marks produced in sand by such waves. Notable is the work by Forel,[1] A. R. Hunt,[2] and G. H. Darwin.[3] The work of these men shows that, when a wave passes over a body of water, the slight oscillation of the water beneath it can be detected to a considerable depth below the surface. To what limit it may extend is unknown. This oscillation sets up small vortices in the water next the bottom, and in the course of time sand ripples are produced by the action of these vortices. These sand ripples are produced at right angles or nearly at right angles to the direction of movement of the wave: that is, they are approximately parallel in direction to the lateral extent of the wave. If the waves on a body of water extend in a northwest-southeast direction (at right angles to the direction of their movement) the ripples generated by them in the sands of the bottom would trend, in general, in the same direction. If we are seeking the factor which controlled the sand ripple directions in the Waverly, we find it directly in the waves which have produced them. It then remains to ask how the direction of water-waves is controlled, and what kept them practically parallel over a wide area throughout a considerable interval of geological time.

Hunt[4] has recorded his observations on ripple direction on the north shore of Torbay which faces the English channel toward the southeast. A portion of the beach examined was so protected

[1] "Les rides de fond," *Archives des Sciences Physiques et Naturelles Genève* (1863). This paper has not been seen by the writer but his results are stated, apparently quite fully, in the paper by Darwin.

[2] "On the Formation of Ripple-Marks," *Proc. Royal Soc. London*, XXXIV (1882), 1–18.

[3] "On the Formation of Ripple-Mark in Sand," *Proc. Royal Soc. London*, XXXVI (1883), 18–43.

[4] *Ibid.*, 6 and 7.

by a breakwater as to receive waves from the southwest only, while farther west along the shore, as the influence of the breakwater became less and less, the waves came from the south and then from the southeast. The beach was examined after a week of calm weather on the day following one on which there had been a slight swell. The sand ripples were found to correspond closely to the direction from which the waves came. Behind the breakwater their trend was northwest-southeast, parallel to the waves coming from the southwest, but as the control of the barrier became less and less to the westward, the ripple directions changed to east and west and then to northeast-southwest, as the waves came from the south, and then from the southeast.

These observations show the independence by wave direction from wind control, the control of wave direction by shore line, and the dependence of ripple direction directly on wave direction.

The parallelism of waves to coasts is generally known, and examples could be multiplied from the beaches of the eastern United States and elsewhere. Since, however, there is no data as to the direction of the ripples induced by these waves, no other need be added here.

In discussing the parallelism of the Bedford-Berea ripples with various persons, it has been suggested that it might indicate the direction of the prevailing wind. In the present geological period the direction of the prevailing winds in Ohio is from the westward. But the actual winds experienced, as a result of the cyclonic control of weather, are so variable that it is impossible to assume that the persistency of the Bedford-Berea ripples could be maintained under similar conditions of cyclonic variation, if those ripples were controlled *directly* by the winds. If they are held to indicate wind direction, we must postulate a series of winds in Bedford-Berea time more uniform in direction, even, than the trade winds, which not infrequently may vary throughout the whole range of the compass in the course of a year, as shown by almost any sailing chart of those regions, and always vary through more than a quadrant of the compass.

On the other hand, granted that the winds initiate the water waves, as soon as they come within the influence of shallow water

they are retarded more in the shallower portions, so that by a process of wave-refraction they are soon brought into a line roughly parallel with the contour lines of the bottom. And the contour lines of the bottom, on all gently sloping coasts, are nearly parallel to the shore line.

The conclusion seems to be warranted that the persistency of direction of the ripples of the Bedford and Berea indicates the prevailing direction of the water waves which formed them, and that this in turn was controlled, either by a shore line or water so shallow as to bring the waves into adjustment parallel to this shore line, or, if it was only shallow water control, to the contours on the sea floor. The shales of the Bedford clearly indicate that there must have been an open sea to the northeastward. Toward the southward the sediments become more sandy and on the whole coarser (the sandstone becomes but slightly coarser but increases very much in relative amount). From this we conclude that either a shore line or shoal water lay toward the southward with decreasing depths of water in that direction sufficient to cause wave refraction. This shore line or the contour of the bottom must have been parallel to the ripple direction, that is, it must have extended in a northwest-southeast direction.

Probably the sea in which these sediments accumulated was of moderate depth, sufficiently so that sedimentation would be continuous. The only evidence of occasional currents which were strong enough to erode locally is found in the middle and upper part of the Berea in central Ohio where the ripples are much less numerous. Quite probably it may have been sufficiently shallow and so well inclosed and protected that currents and waves of oceanic proportions could not develop.

CHANGE IN RIPPLE DIRECTION IN PASSING FROM NORTH TO SOUTH

A brief survey of the map suggests that the directions along the Ohio River tend more nearly east and west than they do farther north. The number of directions occurring within each five degrees has been plotted in four areas. This brings out the fact that there actually is a swing in the direction of the majority of the ripples to more nearly east and west in southern Ohio. In

central Ohio the greatest number trend between N. 50° and 55° W. In Pike and Ross counties by far the greatest number trend from N. 55° to 60° W. In northern Scioto County the maximum is between N. 60° and 65° W., and along the Ohio River it falls between N. 65° and 70° W. The significance of this definite and controlled variation is not apparent at present. The occurrence is merely noted in passing as suggesting one of the methods of attack in such a problem which may yield results.

EVIDENCE FROM THE RIPPLE DIRECTION ON THE ATTITUDE OF THE CINCINNATI AXIS AT THIS TIME

The region of the Cincinnati uplift lies but a few miles to the westward of the area in which the ripples are mapped. This is known to have been a region which from the end of the Ordovician onward tended to maintain a somewhat elevated attitude. According to Schuchert[1] it is one of the positive elements of the continent. That is, it tended to be an island or a region of shallow water while sedimentation was going on in adjacent territories. The axis of the Cincinnati uplift trends nearly north and south, slightly northeast-southwest. With its continuation, the Nashville uplift, the axial trend of the whole is decidedly more northeasterly.

In seeking a coast line which controlled the ripple direction, this positive element suggests itself at once. It has been generally held that there was land in that quarter throughout the Mississippian period and such is indicated on Schuchert's map of this stage.[2] However, by comparing the ripple directions with the present axis of the uplift, as indicated on the outline map of Ohio (Fig. 2), it can readily be observed that the ripples stand almost at a right angle to the axis. If it is supposed that the Cincinnati dome stood high at that time with its axis as at present, it is necessary to assume that within a few miles, certainly not more than 30, to the westward, the ripples were sharply bent into parallelism with this axis. The fact that the ripple direction shows no tendency whatever (the observations are sufficient on this point) to swing into such adjustment to the westward is held to be sufficient

[1] *Bull. Geol. Soc. Am.*, XX (1910), 470.

[2] *Ibid.*, Pls. 78, 79.

evidence that there was no such control in that direction at that time.

Futhermore, the axis which lay to the southward and which did control the ripple directions was directly transverse to the present Cincinnati axis. Whether or not this axis is to be considered as the result of the same forces and conditions which determined the Cincinnati axis, but which were operating in a different manner during Bedford-Berea time, is a question whose answer is, perhaps wholly, a matter of personal opinion. The question is one of some importance in determining the nature of forces and conditions lying back of such a positive element of the continent. The case is of especial interest in view of the fact that, in the Cuyahoga formation which almost directly succeeds the Berea,[1] there is positive evidence of a different nature that the Cincinnati dome had nearly the axial alignment which it holds at present for at least 40 miles north of the Ohio River where the evidence is lost, due to the swinging of the outcrops to the eastward.

In view of the suggestion that the shore line lay to the southward, a word is desirable as to the nature of the Bedford and Berea formations in that direction. W. C. Morse and A. F. Foerste have traced them southwestward into Kentucky for 80 miles and show that the horizon thins rapidly, being reduced at some points to two or three inches.[2] The sandstones and ripple-marks (directions not noted) are still in evidence 18 miles south of the Ohio River where the horizon is only 46 feet thick (as against over 100 in Ohio). Beyond this it is much reduced, and consists almost wholly of argillaceous or calcareous shale, presumably very like the basal Bedford in Ohio.

The authors mention the possibility that only the basal part of the Bedford may be represented in this southern extension, but reject the idea, holding that, even when reduced to two inches, the horizon is "Bedford-Berea." To the writer, who knows the area only from their paper, there seem to be many facts which strongly favor the removal of the Berea and much of the Bedford

[1] The Sunbury black shale, 10 to 20 feet thick, intervenes.

[2] "The Waverly Formations of East Central Kentucky," *Journal of Geology*, XVII, 164–77.

by erosion, prior to the formation of the next succeeding Sunbury shale, and their suggestion cannot lightly be laid aside. These facts are: (1) the presence of a fauna which is found only in the lowermost two or three feet of the Bedford at Gahanna (Franklin County), Bainbridge (Ross County), and Piketon (Pike County), the only localities in central and southern Ohio where the contact has been observed. In Kentucky a portion of the same fauna is found when only a fraction of a foot is present. (2) At one point, Olympian Springs, Bath County, Morse and Foerste note the following variation in thickness of the "Bedford-Berea," within two and one-half miles: $12\frac{1}{2}$ feet, $5\frac{3}{4}$ feet, 2 inches. This is an extreme case but irregularity in thickness is the rule in the sections they present. (3) The absence of beds corresponding to the Berea as soon as the thickness is reduced to less than 70 feet. (It is not apparent that the $7\frac{1}{2}$-foot bed they refer to the Berea in the Elk Lick section, where the total is reduced to 70 feet, is really Berea and not a horizon in the Bedford. Many such occur in the Bedford to the northward.)

It is thus uncertain, and perhaps unknowable except by inference, what the true conditions in Bedford and Berea time were to the southwestward. If, as seems probable to the writer, only the basal beds are present, they are not indicative, for the basal beds throughout southern Ohio are largely shale.

It seems probable that the northwest-southeast axis in Kentucky, which was prominent enough during late Bedford and Berea time to control the ripple directions, was elevated at the close of that period so far as to permit the removal of almost the whole of these deposits. Possibly this uplift did not succeed the formation of the Berea of southern Ohio, but was contemporaneous with it, and the extension of the Berea (so called) over southern Ohio was due to the northward translation of the shallower water deposits resultant on the uplift. No evidence has been brought forward bearing directly on this point.

SUMMARY

The Berea of central and southern Ohio is largely a phase of the Bedford but is readily distinguished by the much greater amount

of sandstone present. Ripple-marks are abundant in the sandstones of the upper half of the Bedford and most of the Berea. From the Ohio River to the center of the state, a distance of 115 miles and over a width of 20 miles, these ripples are remarkably persistent in direction, trending northwest-southeast. In central Ohio the great majority range between N. 40° and N. 55° W. In passing southward the direction swings gradually to more nearly east and west, the majority on the Ohio River ranging from N. 60° to 70° W. The absolute range of observations for the whole region is only 69°. The cause of the progressive variation from north to south is not apparent.

The general persistency of direction is believed to be due to parallelism to the shore line of that time, which lay to the southward, and the direction of the ripples is believed to indicate the approximate trend of this shore line. If such is the case, it is probable that the Cincinnati axis of that time was not appreciable as an uplift, or, if active, maintained an attitude quite different from that holding at present.

The evidence indicates the presence of shoal water, or possibly a land body, to the south-southwestward the axis of which was almost normal to the present axis of the Cincinnati uplift. From the work of Morse and Foerste it seems probable that this axis became more active later, perhaps closing the Bedford sedimentations with uplift and erosion. The Berea of southern Ohio may be the result of the northward pushing of the strand line by this uplift.